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AUTHOR Quinn, Mary Ellen; Kessler, Carolyn
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ABSTRACT

Reported is a study to examine the effects of bilingualism on the ability to formulate scientific hypotheses or solutions to science problems by examining results of the same treatment motivating hypothesis formation given by the same teacher to classes of sixth-grade students ranging from monolingual English-speaking children to proficient bilingual Spanish-English speaking children. Results from these experimental groups were compared with control groups. The treatment given the experimental groups consisted of 12 science inquiry film sessions, and 6 discussion sessions, each 40 minutes in length, with all sessions for all groups taught by the same teacher in English. A significant difference was found between the experimental and control groups for both monolinguals and bilinguals when comparing the scores for quality of scientific hypotheses, with the bilinguals scoring higher. (Author/DS)

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SCIENCE EDUCATION AND BILINGUALISM

Mary Ellen Quinn
Alamo Heights School District, San Antonio, Texas

Carolyn Kessler
The University of Texas at San Antonio

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SCIENCE EDUCATION AND BILINGUALISM

Mary Ellen Quinn and Carolyn Kessler

From two perspectives, that of science education and that of psycholinguistics, this paper presents: 1) evidence that bilingualism has a positive effect on the ability of students to formulate scientific hypotheses or solutions to science problems, 2) offers a possible explanation for that positive effect, and 3) suggests some implications for science education for linguists engaged both in teaching and research.

Contemporary models of science education with their focus on inquiry give a critical role to divergent thinking and the ability to formulate hypotheses in problem-solving situations. The acquisition and development of good hypothesizing abilities are, therefore, essential aspects of an effective science curriculum, along with the abilities to make accurate, detailed observations, enlightened inferences, and an adequate selection of variables.

In solving problems, students must select and order varied types of information or data, presumably by using concepts that they know. Inquiry addresses itself primarily to using concepts, only secondarily to learning concepts; clearly, however, an end product of any inquiry process may be the development of a new idea or concept. Science education, then, is concerned with making students more effective inquirers who effeciently make use of the abilities which serve as precursors to problem-solving.

In asking if these abilities can be taught, researchers have in-

vestigated the effects of instruction on various processes utilized in science problem-solving activities. Quinn (1971) and Quinn and George (1975) have shown that students can improve their hypothesizing abilities if criteria for developing hypotheses are illustrated through problem-oriented filmloops which tap divergent thinking processes. Wright (1978) has shown that intensive instruction, instruction through an event that creates a discrepancy between the observer's expectations and the information received, evokes conflict and response uncertainty, leads to an increased capacity for problem-solving. Pouler and Wright (1980) have also shown that hypothesis-forming behaviors can be taught effectively as part of normal classroom instruction by providing students with criteria of acceptable hypotheses and differential reinforcements. Other studies (Salomon, 1970; Klein et al, 1961) have suggested that hypothesizing skills can be enhanced by various forms of intensive instruction.

None of the studies cited above, however, take into account the linguistically different child, in particular, the large number of bilingual children in schools throughout the United States.

It is the purpose of this paper to examine the effects of bilingualism on the ability to formulate scientific hypotheses or solutions to science problems by examining results of the same treatment motivating hypothesis formation given by the same teacher in intact classrooms of sixth-graders ranging from monolingual English-speaking children to proficient bilingual Spanish-English speaking children. Results from these experimental groups are compared with control groups. Bilingual children are here defined as

those children who can produce complete and meaningful utterances in two languages (McLaughlin, 1978). While earlier studies on the effects of bilingualism characteristically reported the negative consequences for cognitive functioning, more recent studies dating from the early 1960's generally indicate positive consequences on the development of nonverbal and verbal abilities, cognitive flexibility and divergent thinking skills. (See Cummins, 1976, for a review of the literature.) Furthermore, Duncan and De Avila (1979) found a positive and significant relationship between the degree of linguistic proficiency and the cognitive-perceptual performance of children, with proficient bilingual children consistently outperforming groups identified as partial bilingual, monolingual, and late language learners.

Lambert (1977) has suggested that the consequences of bilingualism may be dependent on the dominance relationship of the bilingual's two languages. He distinguishes between additive bilingualism, the adding of a second language without loss of the first, and subtractive bilingualism, the adding of the second language at the expense or loss of the first. Relatively few studies have examined the effects of these differing types of bilingualism on cognitive functioning. Cummins (1976, 1979) has argued that there may be threshold levels of linguistic competence that bilingual children must attain before they can experience the potentially positive effects of bilingualism on cognitive functioning.

The framework for investigating the ability of bilingual children to formulate scientific hypotheses is set forth in a study by Quinn (1971) and

Quinn and George (1975), which evaluated a method for teaching hypothesis formation to sixth-grade children in two different socio-economic settings.

Table 1 outlines the experimental design.

TABLE 1

EXPERIMENTAL DESIGN

	Sequence of Procedures		
	1	2	3
Control Group	Covariable Test	Criterion Variable Test	Treatment
Experimental or Treatment Group	Corvariable Test	Treatment	Criterion Variable Test

Table 2 gives the design for comparing socio-economic levels of treatment groups.

TABLE 2

TWO BY TWO FACTORIAL DESIGN TO COMPARE TREATMENTS AND SOCIO-ECONOMIC LEVELS

	Socio-Economic I	Socio-Economic II
Treatment	(1 1) [a]	(1 2)
No Treatment	(2 1)	(2 2)

[a]Cell code

Quinn concluded that the formulation of scientific hypotheses can be taught, that the quality of the hypotheses elicited can be measured, and that a significant difference ($p < .001$) exists between the quality of hypotheses generated by students who received instruction in hypothesis formation and those who did not as shown in Table 3.

TABLE 3

ANALYSIS OF COVARIANCE FOR TREATMENT AND SOCIO-ECONOMIC LEVEL

Source of Variation	Adjusted SS	DF	MS	F	P Less Than
Treatment	34453.320	1	24453.320	113.698	0.001
Socio-economic Level	0.084	1	0.094	0.000	0.986
Treatment X S-E LEVEL	172.648	1	172.648	0.570	0.451
Within Cells	51817.242	171	303.025		

Findings from four groups of sixth-grade children in Philadelphia, Pennsylvania, a control and an experimental group from an upper middle class suburban socio-economic level and a control and an experimental group from a lower working class urban socio-economic level indicated that the

cognitive ability to formulate scientific hypotheses functions independently of socio-economic level (See Table 3).

With socio-economic level identified as a non-significant variable in the ability to generate increasingly complex scientific hypotheses, Kessler and Quinn (1979) conducted a pilot study comparing the effects of non-balanced bilingualism in Italian and English, the dominant language, with monolingualism in English on the ability to formulate scientific hypotheses. Using an experimental group for which all procedures as well as the teacher were held constant, results obtained from 28 sixth-graders in an intact classroom in a low socio-economic area of Philadelphia indicated that the ability to generate hypotheses favors bilinguals, even when bilingualism is subtractive. The sample used in this exploratory study of the effects of bilingualism on formulating scientific hypotheses included a group of 14 English-speaking monolingual children and 14 Italian English bilinguals in the process of replacing their first language, Italian, with English. Both groups were matched on I.Q. scores as measured by the Otis Quick-Scoring Mental Ability Test, Beta, Form FM. All of the children came from a low socio-economic neighborhood in which the school was situated.

The observed positive effects of non-balanced or subtractive bilingualism leads to questions regarding the effects of additive, proficient bilingualism on children's ability to formulate scientific hypotheses. This report, part of an extended study, compares the effects of teaching hypothesis formation to bilingual children proficient in both Spanish and English with results from monolingual English-Speaking children.

Participants

The principal part of this study, then, focuses on two groups of bilingual children, one control and one experimental group, and two groups of monolingual children, one control and one experimental group. In addition, results obtained from the two groups in the pilot study, one subtractive bilingual group and one monolingual group, are also reported.

The proficient, additive bilingual groups were from a Mexican-American neighborhood in San Antonio, Texas. One control and one experimental group of 30 students each were from intact sixth-grade classes in the same school in a very low socio-economic area where Spanish functions as the language of the home and the community. Language proficiency tests designed by the school district and administered at entry into kindergarten had identified the students in the sample at that time as Spanish dominant with little or no proficiency in English. As a result, they were placed in bilingual education programs for grades K-3. By grade 6 all instruction was in English, the second language, but Spanish continued to function in peer interactions, in the home, and in the community. Because of the bilingual program in which the children had participated, they were literate in both Spanish and English. The control and experimental groups were matched on mathematics scores, science scores, and reading scores, all as measured by the Comprehensive Test of Basic Skills, Level 2, Form S.

For the monolingual English-speaking children from a high socio-economic level in an upper middle class area of suburban Philadelphia, one control and one experimental group of 32 students each were monolingual

English speakers. In addition to socio-economic level, the two groups were matched for grade level as well as the following variables: 1) I.Q. as measured by the Otis Quick-Scoring Mental Ability Test, Beta, Form FM; 2) reading scores as measured by Part III of the Pupil Progress Series, Diagnostic Reading Test; 3) overall grade-point average.

Methodology

The treatment given the experimental groups consisted of 12 science inquiry film sessions and 6 discussion sessions, each session 40 minutes in length, with all sessions for all groups taught by the same teacher in English. Each film session utilized a 3-minute film loop of the Inquiry Development Program in Physical Science developed by Suchman (1962), and each depicts a single physical science problem. Suchman's program for developing inquiry processes in children begins with the presentation of a problem through a short film or actual demonstration. The event presented is one which sets up a discrepancy for the student, leading to inquiry and seeking an explanation to resolve the discrepancy. In serving as the source of data to explain the observed event, the teacher invites questions from the students to which the response is either yes or no. The problem presentation sessions ended with the students writing as many hypotheses as possible in a rigorously controlled 12-minute period. All of the hypotheses generated by each student were then scored for quality using Quinn's Hypothesis Quality Scale (1971). In the follow-up discussion sessions students critiqued which questions were effective and why as they were guided by the teacher through an analysis of the problem, determination

of the relevance of facts gathered, and assessment of the quality of their hypotheses. Children in the experimental groups were shown how to judge their own hypotheses and how to make use of their observations and inferences to generate hypotheses of higher quality as measured on Quinn's scale given in Table 4.

TABLE 4

HYPOTHESIS QUALITY SCALE

Points Given	Criterion
0	No explanation, such as a non-sense statement, a question, an observation, a single inference about a single concrete object.
1	Non-scientific explanation, such as "...because it's Magic" or "...because the man pushed a button."
2	Partial scientific explanation, such as incomplete reference to variables, a negative explanation, an analogy.
3	Scientific explanation relating at least two variables in general or non-specific terms.
4	Precise scientific explanation, a qualification and/or quantification of the variables.
5	Explicit statement of a test of an hypothesis. (An inference is made here that the child who states a test is also able to adequately and precisely hypothesize.)

Quinn validated the definition of an hypothesis as a testable explanation of an empirical relationship between at least two variables in a given problem situation through analyzing the philosophy of science literature, using in particular the works of Poincaré (1952), Popper (1959), Hanson (1968), Caws (1969), and Black (1946). From these works she synthesized the following criteria for judging the quality of a hypothesis: 1) it makes sense, 2) it is empirically based, 3) it is adequate, 4) it is precise, and 5) it states a test of its validity. Based upon the criteria for evaluating hypotheses, the scale reflects a continuous variable with a zero to five range for scoring each hypothesis. A zero score is given for no explanation (i.e., a nonsense statement, a question, an observation, a single inference about a single concrete object); one for a non-scientific explanation (i.e., '...because it's magic'), two for a partial scientific explanation (i.e., incomplete reference to variables, a negative explanation, an analogy); three for a scientific explanation relating at least two variables in general or nonspecific terms; four for a precise scientific explanation, a qualification and/or quantification of the variables; five for an explicit statement of a test for a precise scientific explanation. Quinn found an interrater reliability of .94 using the Nash-Beyers computer program based on Winer (1962) as shown in Table 5.

TABLE 5

INTERJUDGE RELIABILITY OF THE HYPOTHESIS

QUALITY SCORING SCALE

Source of Variation	Sum of Squares	D F	Mean Square	F
Among Subjects	367.840	49	7.507	
Within Subjects	43.333	100	0.433	
Among cols. 0.653		2	0.327	0.750
Residual 42.680		98	0.436	
TOTAL	411.173	149		

Column Number	Mean	Standard Deviation
1	2.460	1.775
2	2.560	1.527
3	2.620	1.701

Unadjusted reliability = 0.942

Results

Hypothesis quality means for the monolingual and bilingual experimental groups together with the means for the pilot groups (subtractive bilinguals)

are presented in Table 6.

TABLE 6

MEANS FOR MONOLINGUAL AND BILINGUAL EXPERIMENTAL GROUPS

Variable	Monolinguals (N=32)	Bilinguals	
		subtractive (N=14)	additive (N=30)
Hypothesis Quality	41.29	48.07	176.00

These results are presented graphically in Figure 1.

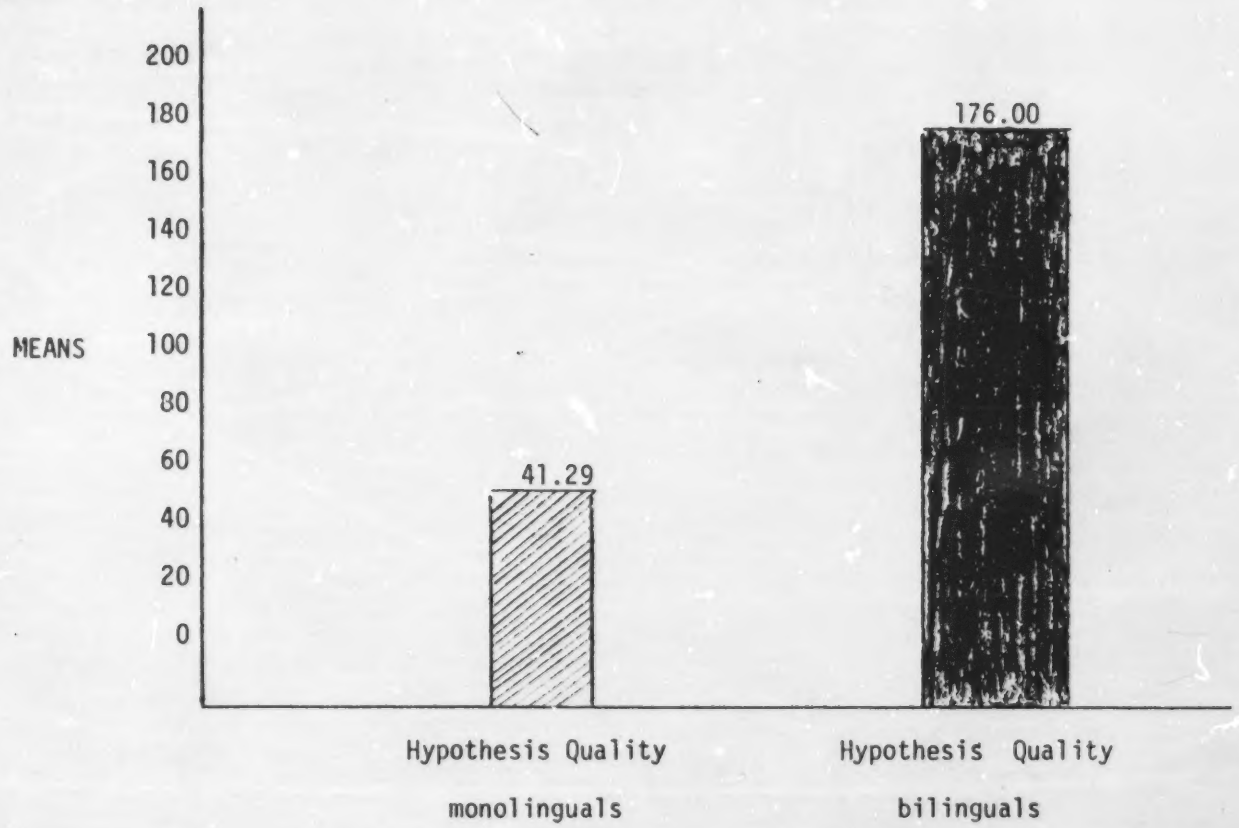

Figure 1. Comparison of monolinguals and bilinguals on scores for quality of scientific hypotheses

The difference in means between the experimental and control groups for both monolinguals and bilinguals are significant at the 0.001 level when analysis of covariance is performed with reading grade equivalent used as covariant.

Explanation of Results

One explanation of the hypothesis that bilingualism can influence the acquisition of cognitive abilities can be found in Piaget's theory

of cognitive development. Even though Piaget takes a conservative position on the developmental relationship between language and thought, that position does not seem to deny that bilingualism can represent an enriched form of experience capable of influencing cognitive functioning positively. In Piaget's theory, discrepant events, such as those presented in science problems, assume a critical function in establishing the type of internal conflict necessary for intellectual development. In the Piagetian sense, one may view instruction in the generation of hypotheses as an effort to facilitate the learner's movement to a higher cognitive level of inquiry (Feldman, 1980). Furthermore, Piaget's theory attributes an increasingly important role to language in implementing abstract thought in the stages of concrete operational thought and formal operations, stages characteristically represented by the sixth-grade 11-year-olds in this study. The role of internal conceptual conflict in cognitive development, as Piaget (1970) explains, is crucial to the position underlying this study that conceptual conflict, which triggers the processes of assimilation and accommodation needed for cognitive development, is stronger for the bilingual child than for the monolingual. In other words, that external event which sets up an internal disequilibrium is very central to cognitive reorganization and development. Science problem-solving situations, where the emphasis is upon both the quantity and quality of output, can produce fluency, flexibility, and originality as well as quality and relevance. This view of divergent thinking provides an operational definition of certain aspects of creativity viewed as a process (Feldman, 1980).

The sixth-grade preadolescent 11-year-olds participating in this study represent, according to the Piagetian stages of cognitive development, a transitional stage between concrete operations and formal operational thought. According to Inhelder and Piaget's (1958) analysis, the development of formal operations begins in the preoperational period, roughly about age 5, continues throught the concrete operational period between ages 7 and 11, and ends in the formal operational period between approximately ages 12 and 15. Children in concrete operational thought understand qualitative but not quantitative relationships whereas those in formal thought are described as understanding both qualitative and quantitative relationships and as having some notion of the relevant theoretical constructs. From about age 5 children's problem-solving strategies are rule-governed, with the rules progressing from less complex to more complex with age. Furthermore, a number of studies (Siegler, 1978) suggest that there is a substantial difference between what children typically know and what they are capable of learning. A basic question raised by these findings is whether older children's superior learning reflects more advanced initial knowledge or whether it reflects a more general learning ability. In a study with 5-year-olds and 8-year-olds Siegler (1976) found that through instruction it was possible to change the younger children's encoding of variables necessary to solve a science problem and that when this condition was met, both age groups benefited from the experience with conflict problems that had previously benefited only the older group.

In Piagetian terms, the disequilibration arising from two linguistic

inputs may stimulate the developing bilinguals to work actively to re-establish equilibrium through the processes of assimilation and accomodation. In the hypothesizing processes of language development, the increase in ability to observe details required by the dual language input and consequent increase in uncertainty in responding enhances the conflict between possible hypotheses regarding the linguistic rules. That state of conflict is relieved by generating additional and more acceptable hypotheses until, as an end result, the two linguistic perspectives of the bilingual are encoded. This experience, albeit subconscious, in language hypothesis generation may have a similar effect upon the capacity to generate scientific hypotheses.

Implications

These results, of course, have implications for language education as well as science ducation, for linguists as well as physicists, and for teachers of English as a second language as well as the science teachers who instruct bilingual students. This study suggests, among other things, that students educated in more than one language will be better problem-solvers than their monolingual peers. And for science educators at all levels this could mean the active recruitment of bilingual students for all areas of science. For linguists, language educators, researchers and language teachers it could also mean a closer working relationship with natural scientists and science educators and researchers.

Studies such as this also suggest implications for the bilingual child whose internal contradictions arising from the acquisition of two linguistic codes may lead to more general learning abilities. The present

study focuses on children's ability to formulate scientific hypotheses as a central process in the solution of science problems. And it further suggests that certain relevant aspects of science problem situations involving discrepant events may be brought to the bilingual child's attention by the availability of two different linguistic perspectives.

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